Incidence and Spread of Insects from Bucket Elevator Leg Boots

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Ph.D. Dissertation Defense

Wednesday, January 30, 2013

8:00 AM, SH 204

Comparing Elevators and Feed Mills

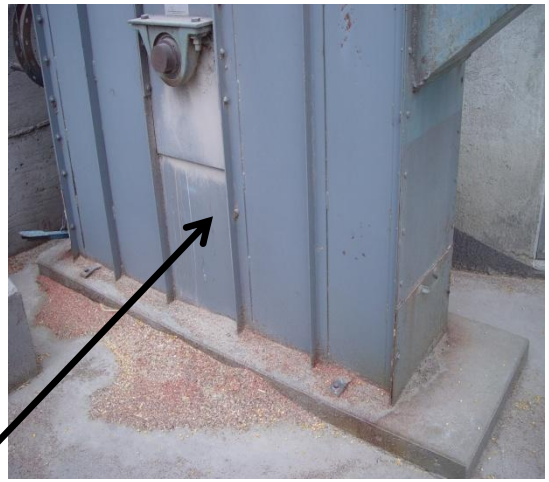
Elevators

- Receiving and storing large volumes of grain
- Elevate grain from an underground receiving pit to the top of the facility and distributed to different storage bins

Feed mills

- Divided into various cost centers including: receiving, material processing, mixing, pelleting, packaging, warehousing, and loading
- Production areas are used to process raw grains and minor ingredients into feed materials

Elevator Leg, Boot, and Pit Areas



Boot and pit area

Elevator leg

- Enclosed leg casing used to elevate grain to the top of a facility and discharge to other areas

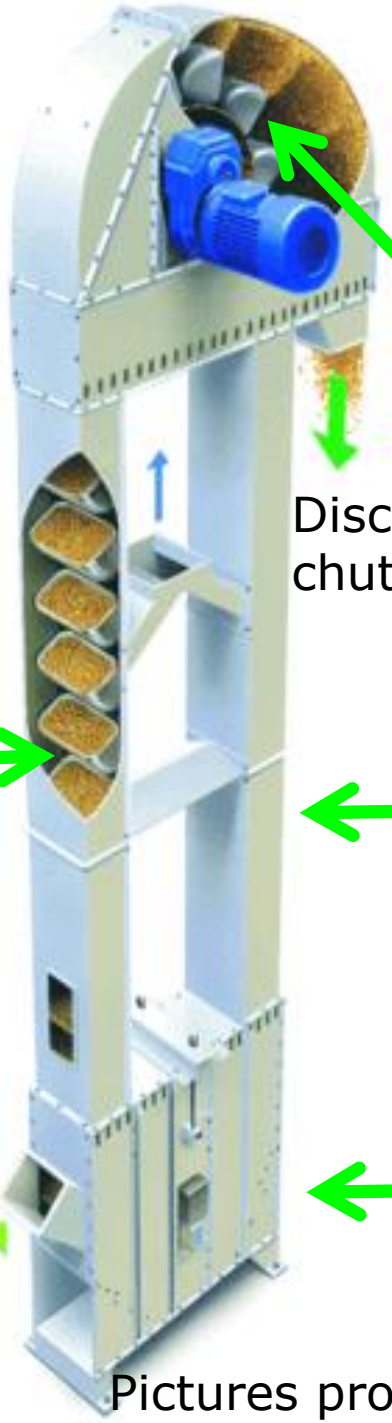
Boot

- Enclosed base of an elevator leg casing where residual (static) grain accumulates after the first loading
- Provides an ideal habitat for insect population growth and development

Pit

- Area surrounding elevator boot and is usually located in a subterranean location
- If grain is allowed to accumulate, this becomes an ideal habitat for insect infestation

Bucket Elevator Components



Head section

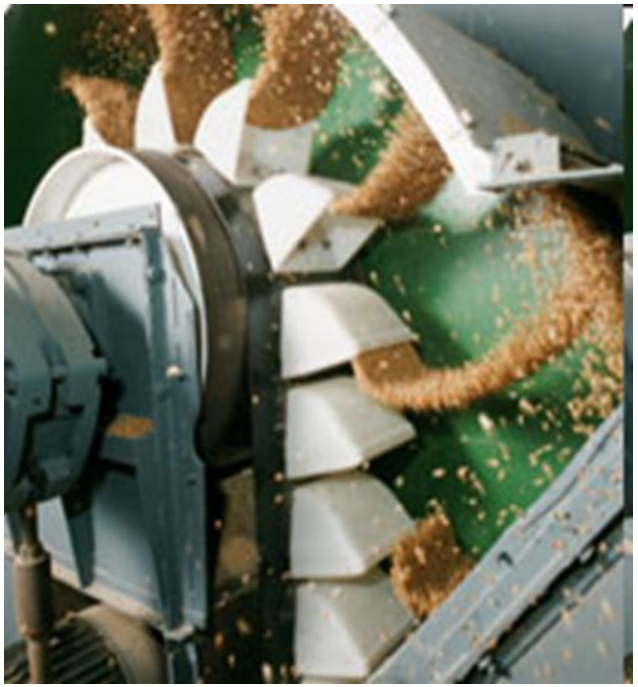
Discharge chute

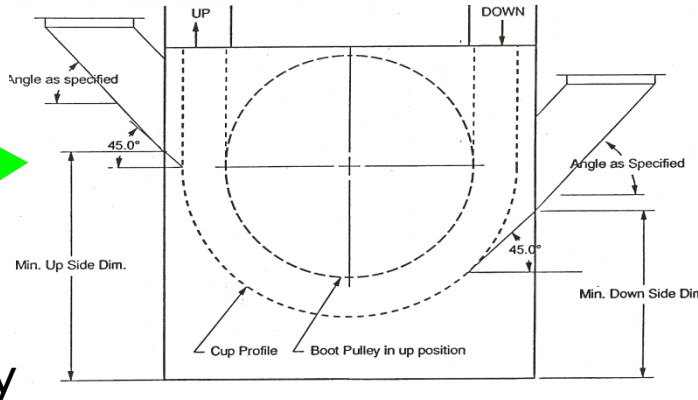
Belt + Buckets

Leg/trunk

Boot section

Front feed





Pictures provided by Dr. A. Kinglsy

Stored-Product Insects Commonly Found in the Boot-pit Area

Lesser grain borer
(*Rhyzopertha dominica*)

Rusty grain beetle
(*Cryptolestes ferrugineus*)

Red flour beetle
(*Tribolium castaneum*)

Rice weevil
(*Sitophilus oryzae*)

Good (1937) sampled 19 flour mills and found high densities of *T. castaneum*, *S. oryzae*, and *R. dominica* in the boot-pit area

Arthur (2006) found high densities of *S. oryzae*, *T. castaneum*, and *C. ferrugineus* in the boot-pit area

Rationale for the Study

- **Grain elevator and feed mill facilities are ideal habitats for stored-product insect pests**
  - Constant availability of abundant food sources
  - Shelter and relatively warm environments
- **Previous grain elevator and feed mill insect pest surveys**
  - Prior to flour mill facility fumigation, boot cleaning was recommended to manage insect pests in this area (Good, 1937)
  - Cleaning empty storage bins reduced insect population densities in discharge spouts (Reed et al., 2003)
  - Grain residue samples from the boot-pit and tunnel areas have high insect densities (Arthur et al., 2006)
  - Quality of sanitation practices were highly correlated with insect populations (Dowdy and McGaughey, 1998)

Rationale for the Study (continued)

- **Common sanitation practices in the elevator boot and pit area**
  - Removal of residual grain
  - Residual insecticidal chemical spray applications
- **Commercial grain elevator and feed mill facilities boot and pit areas contribute to commingling of insects with grain that moves through the elevator leg and could be a function of**
  - Time
  - Initial density of insects infesting the boot-pit areas

Research Objectives

1. **Measure the magnitude of insect commingling as a function of stored-grain insect density levels in wheat and corn using a modified pilot-scale bucket elevator leg**
   - Identify the dynamics that can lead to the spread of infestations from the boot-pit area to other areas of a facility (bins)
   - Examine the impact of residual insecticide application to the boot on commingling insect densities

2. **Determine temporal changes of stored-grain insect populations in commercial facilities (elevators and feed mills) over a two-year period**

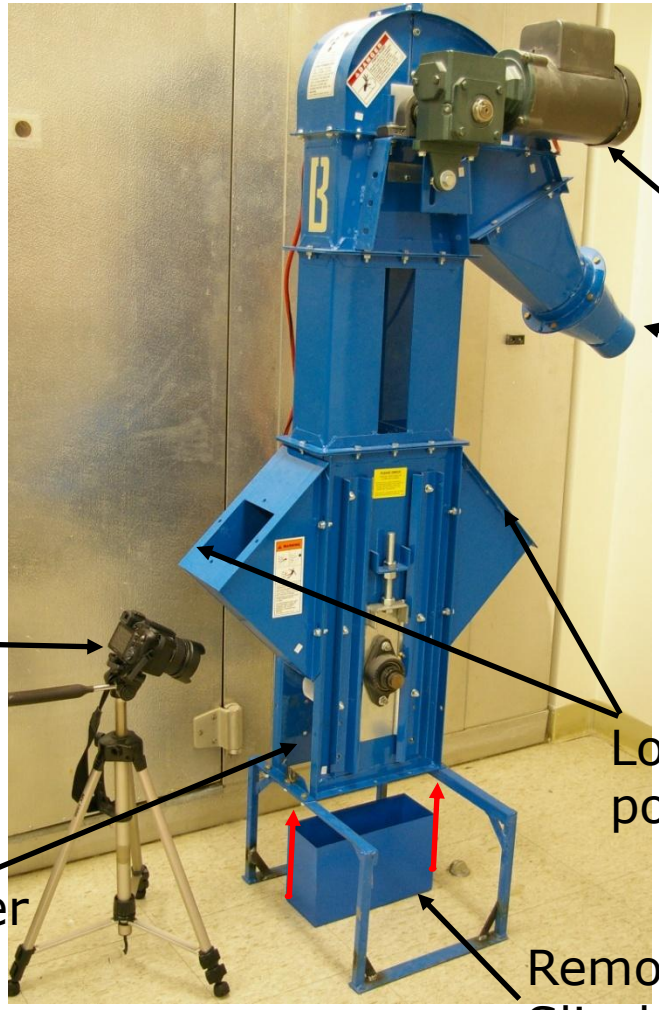
Research Objectives
(continued)

3. **Compare costs associated with a grain facility sanitation program**
   - Identifying the most cost effective and economical pest management practices for either a feed mill or an elevator facility
   - Reduce risks associated with insect commingling in the boot and pit areas

Objective 1: Measurement of Insect Commingling

- Development of a novel slip-boot design for a bucket elevator leg
- Laboratory tests using a pilot-scale bucket elevator leg

Pilot-scale Bucket Elevator Leg



Boot area

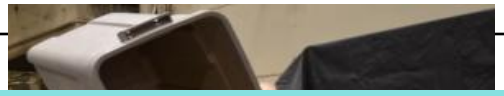
Pilot-scale Bucket Elevator Leg (continued)

- **Grains tested**
  - Wheat
  - Corn
- **Insect densities**
  - 0, 150, 300, 600 insects per kg
- **Incubation time for infested boot: (time allowed for insect population development)**
  - 0, 8, 16, 24 weeks
- **Insecticide treated slip-boots**
  - β-cyfluthrin sprayed at high label rate of 20 mg(AI)/m^2
  - Slip-boots infested at the highest density level

Pilot-scale Bucket Elevator Leg (continued)

Discharge (transfer) grain was collected after transferring over an infested slip-boot

Discharge Grain was Processed Twice Through an Insectomat®



Repeat sieving after an 8-week incubation, allowing internal (hidden) insects to emerge.

- **Initial sieving – external insects collected**
- **8-week sieving – internal insects collected**

In
fe
in

Clean

Pan containing sieved insects

Adult insects that commingled with the clean grain transfer were enumerated, after sieving

Insect Species (Boot residual grain)

Wheat:

Lesser grain borer
(*Rhyzopertha dominica*)

Rusty grain beetle
(*Cryptolestes ferrugineus*)

Red flour beetle
(*Tribolium castaneum*)

Corn:

Rice weevil
(*Sitophilus oryzae*)

Sawtoothed Grain beetle
(*Oryzaephilus surinamensis*)

Red flour beetle
(*Tribolium castaneum*)

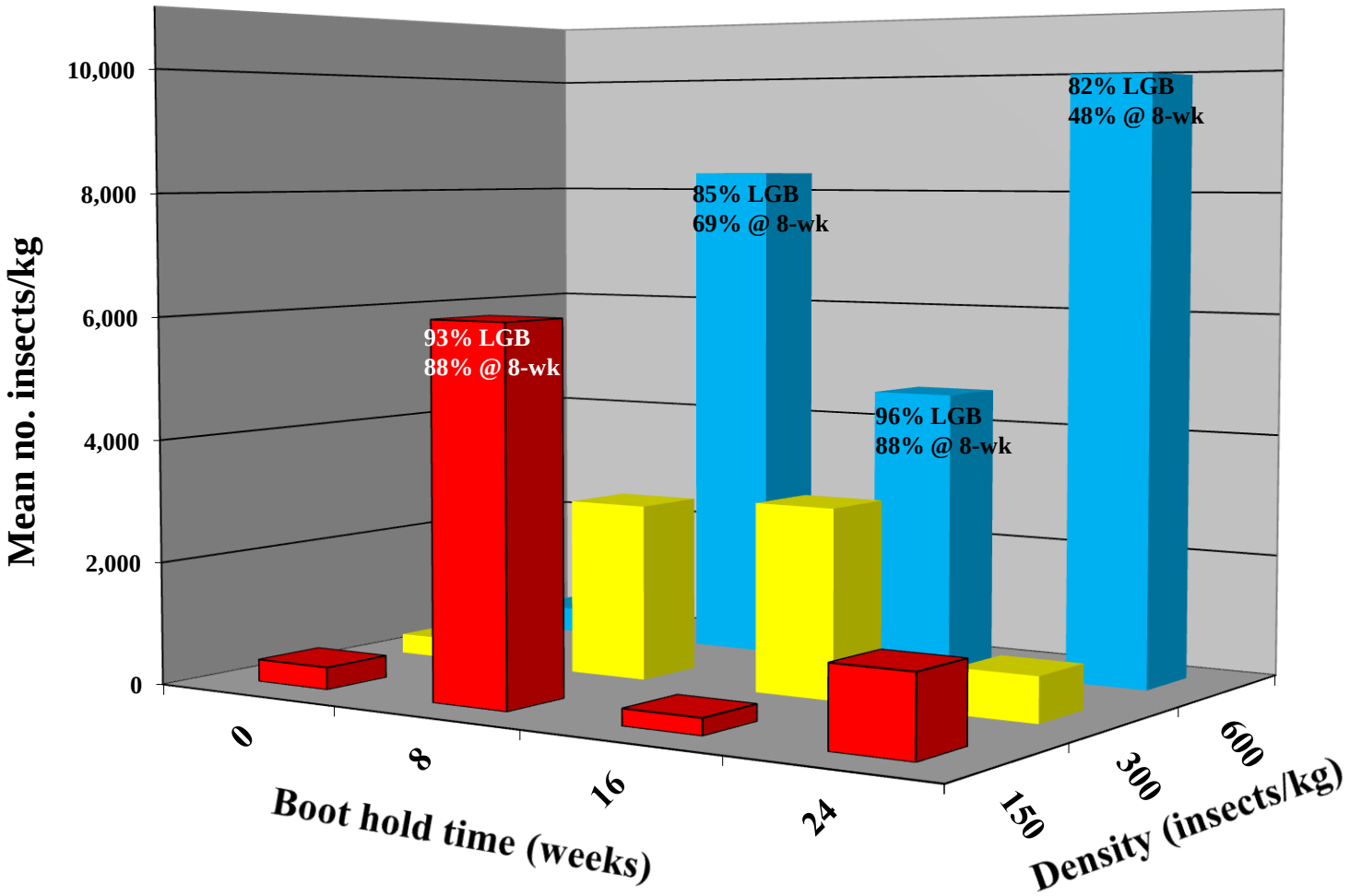
Two-way ANOVA for Wheat Samples

Location	Sieving period	Calendar period	*F*-value	df	*P*-value
Boot	**Initial**	**Density**	**9.14**	**2, 24**	**0.0013***
		Boot hold time	**8.84**	**3, 24**	**0.0003***
		Density x boot hold time	**4.90**	**6, 24**	**0.0021***
	After 8 wk	**Density**	**2.97**	**2, 24**	**0.0705**
		Boot hold time	**2.57**	**3, 24**	**0.0778**
		Density x boot hold time	**0.88**	**6, 24**	**0.5271**
Transfer	**Initial**	**Density**	**0.36**	**2, 24**	**0.2222**
		Boot hold time	**0.45**	**3, 24**	**0.3541**
		Density x boot hold time	**1.37**	**6, 24**	**0.4522**
	After 8 wk	**Density**	**1.57**	**2, 24**	**0.7034**
		Boot hold time	**1.28**	**3, 24**	**0.2522**
		Density x boot hold time	**1.45**	**6, 24**	**0.4559**

*Significant ($P < 0.05$)

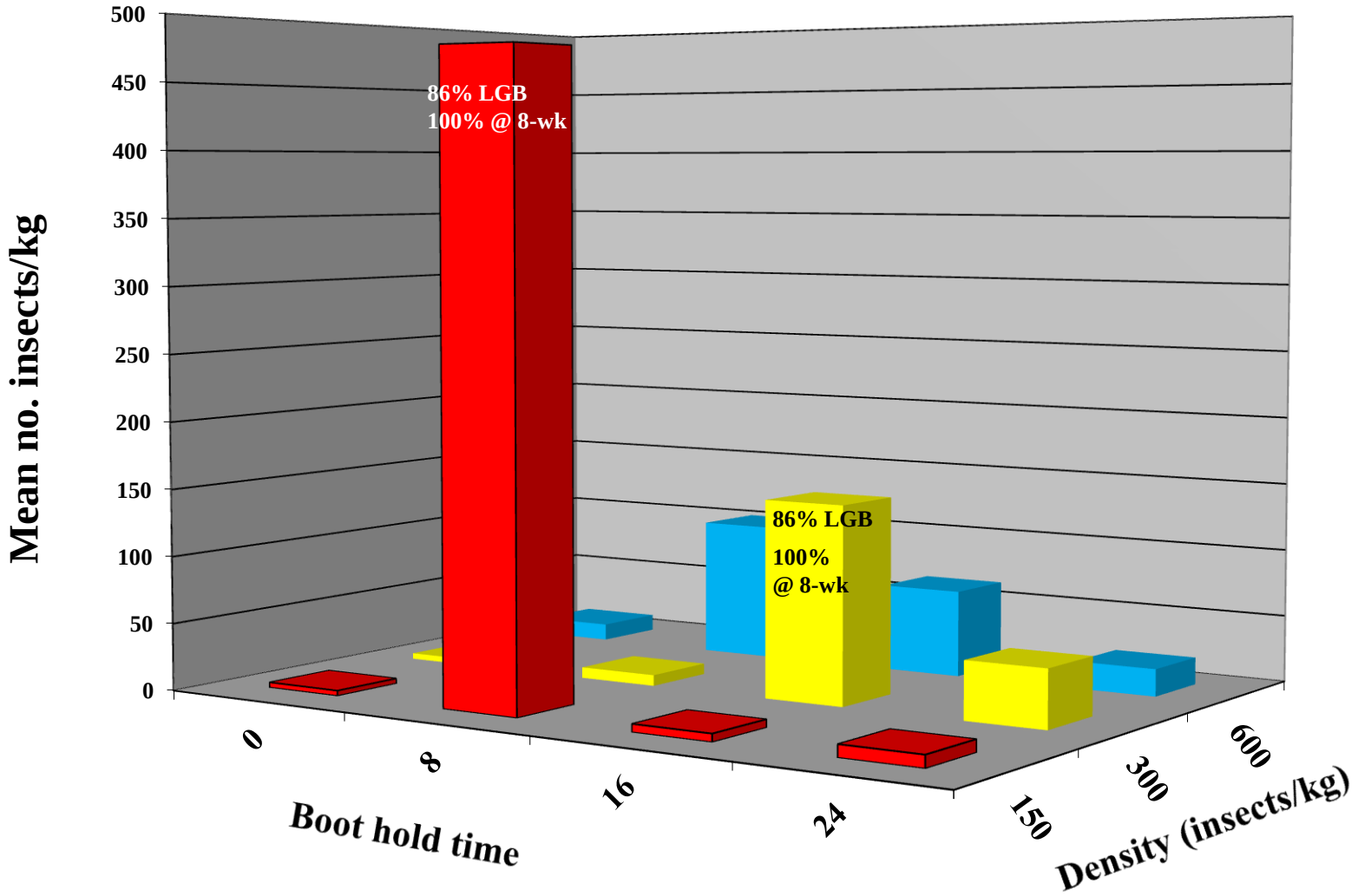
Wheat Boot

Insect counts after 8-wk of incubation

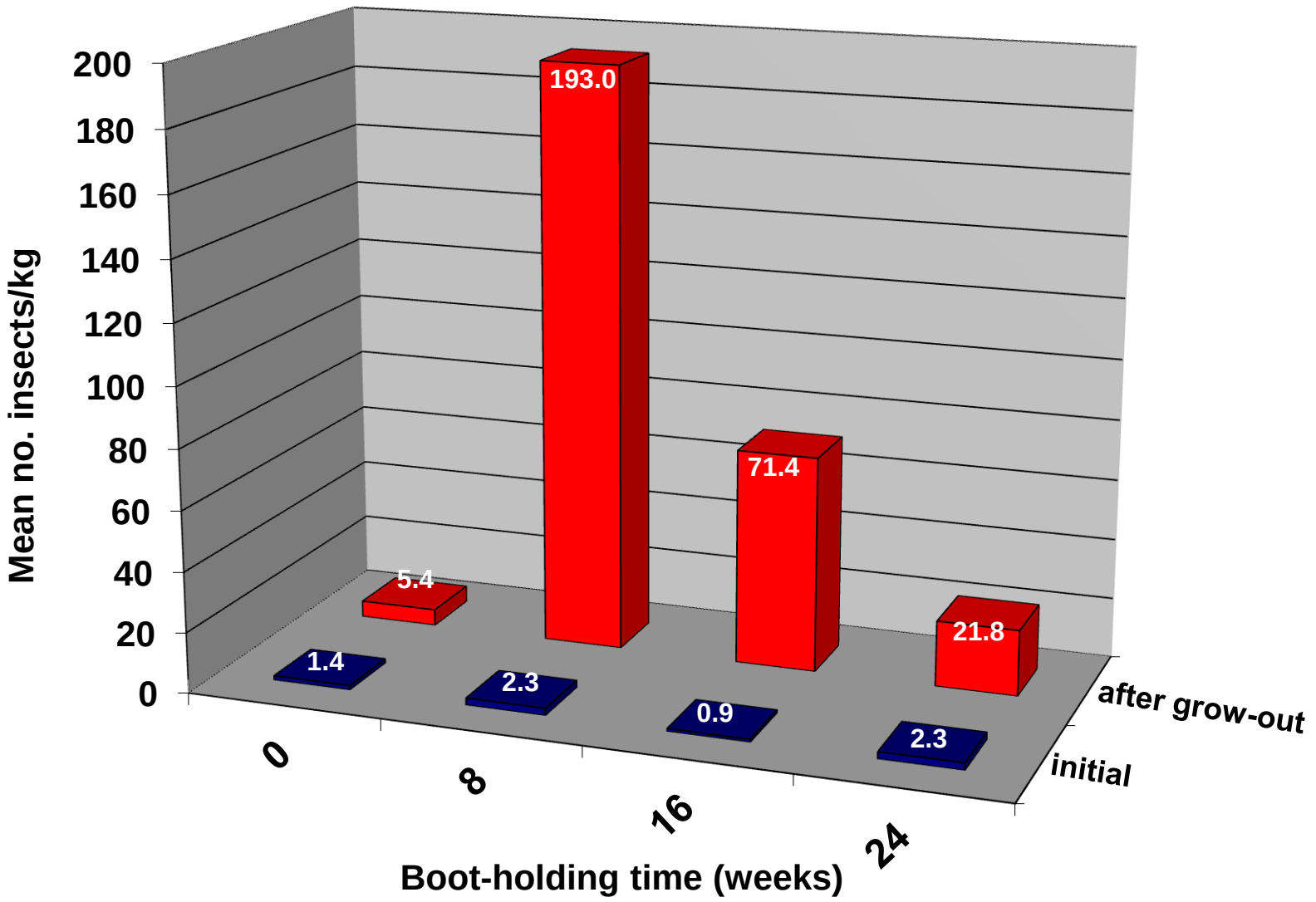


Wheat Transfer

Insect counts after 8-wk of incubation

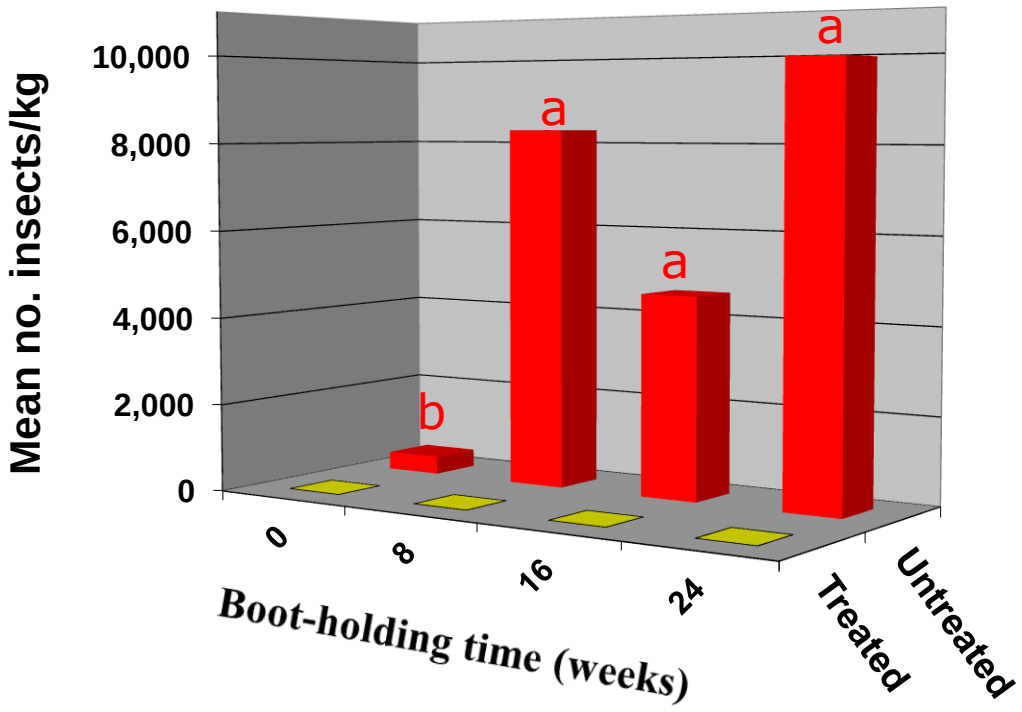


Insect Counts in Wheat



Chemical Spray Treatment

Insect counts in the wheat boot: Treated vs. Untreated

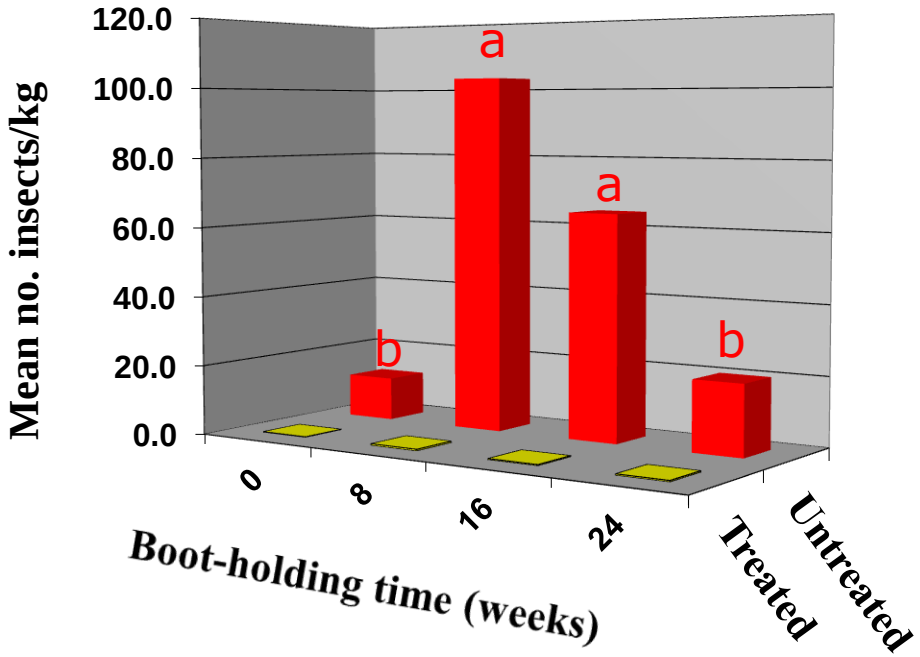


2-way ANOVA	*F* – value	*df*	*p* - value
Treatment	535.5	1, 16	0.0001*
Boot-hold time	5.29	3, 16	0.0100*
Treatment x boot-hold time	4.71	3, 16	0.0153*

*Significant ($P < 0.05$)

Chemical Spray Treatment

Insect counts in wheat transfers: Treated vs. Untreated



2-way ANOVA	*F* – value	*df*	*p* - value
Treatment	46.16	1, 16	0.0001*
Boot-hold time	0.56	3, 16	0.0005*
Treatment x boot-hold time	0.35	3, 16	0.0164*

*Significant ($P < 0.05$)

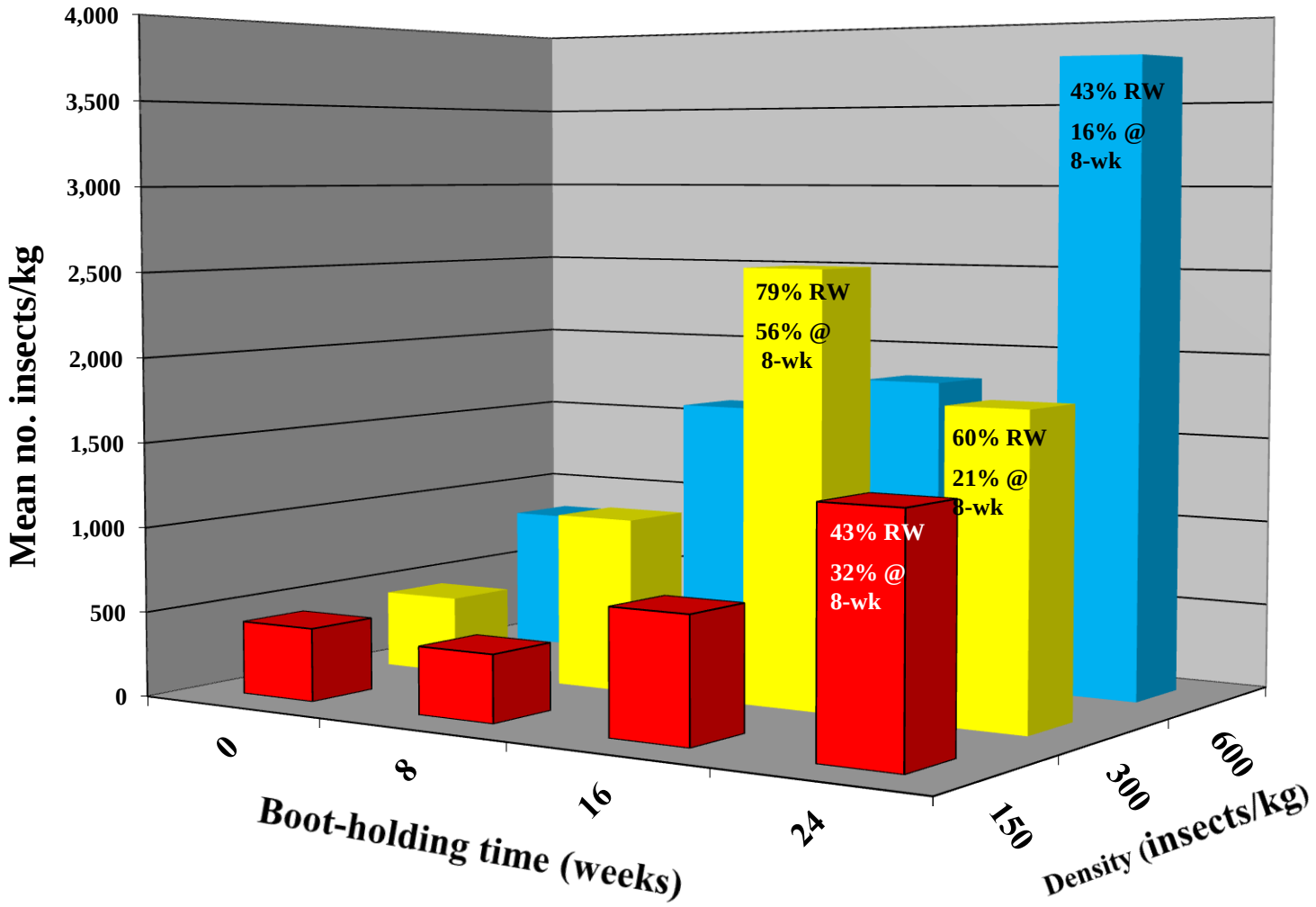
Two-way ANOVA for Corn Samples

Location	Sieving period	Source	F-value	df	*P*-value
Boot	Initial	Density	1.03	2, 24	0.3727
		Boot hold time	1.99	3, 24	0.1431
		Density * boot hold time	0.37	6, 24	0.8887
	After 8 wk	Density	3.40	2, 24	0.0500
		Boot hold time	2.77	3, 24	0.0634
		Density * boot hold time	1.75	6, 24	0.1529
Transfer	Initial	Density	0.69	2, 24	0.3976
		Boot hold time	1.09	2, 24	0.3715
		Density * boot hold time	0.75	6, 24	0.5557
	After 8 wk	Density	1.08	2, 24	0.5759
		Boot hold time	3.529	6, 24	**0.0302***
		Density * boot hold time	0.75	6, 24	0.6566

*Significant ($P < 0.05$)

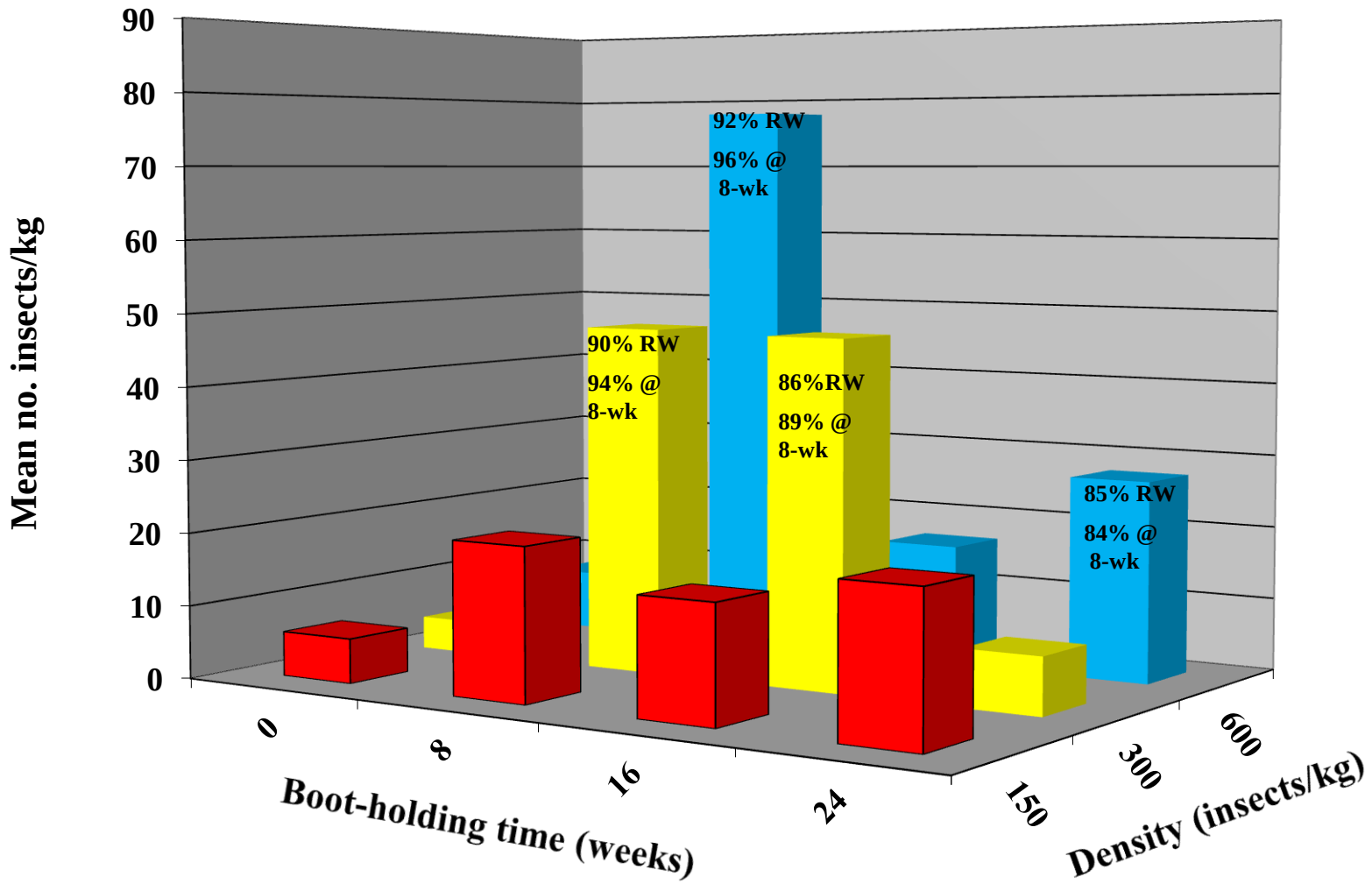
Corn Boot

Insect counts after 8-wk incubation

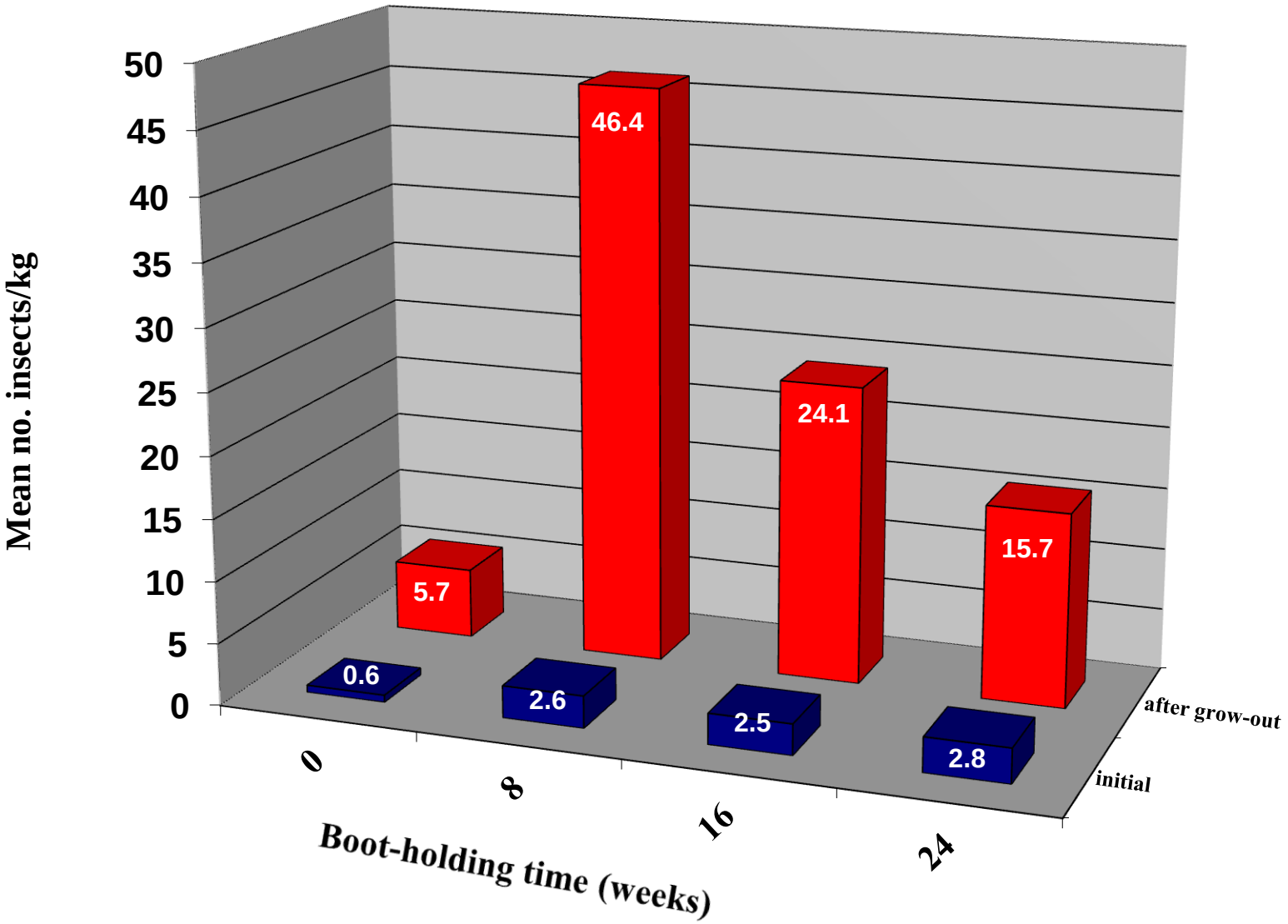


Corn Transfer

Insect counts after 8-wk incubation

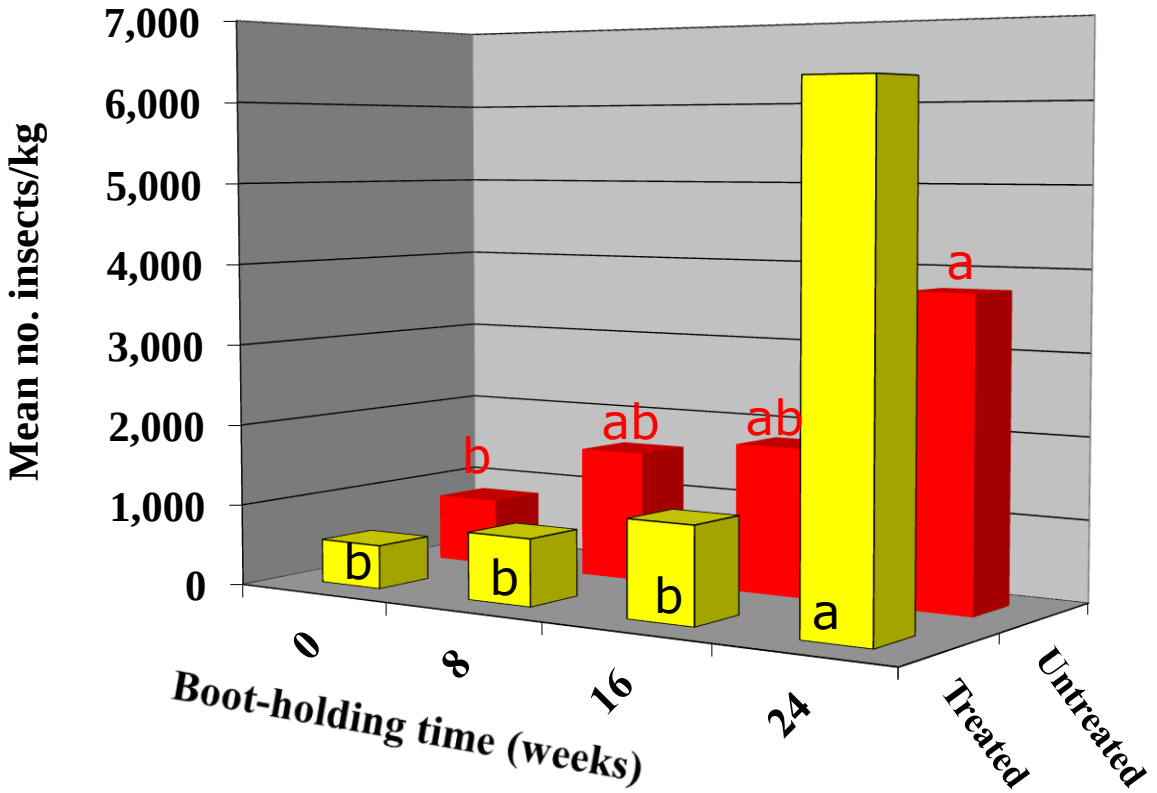


Insect Counts in Corn



Chemical Spray Treatment

Insect counts in the corn boot: treated vs. untreated

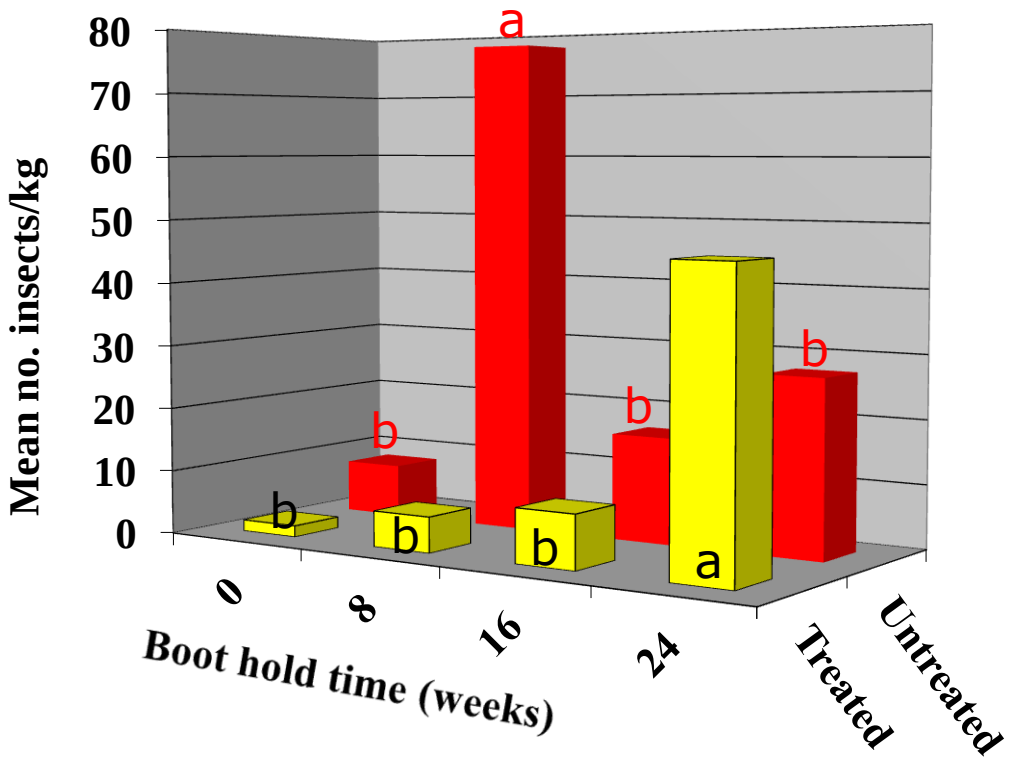


2-way ANOVA	*F* – value	*df*	*p* - value
Treatment	2.33	1, 16	0.1461
Boot-hold time	3.43	3, 16	0.0425*
Treatment x boot-hold time	2.24	3, 16	0.1232

*Significant ($P < 0.05$)

Chemical Spray Treatment

Insect counts in the corn transfer: treated vs. untreated



2-way ANOVA	*F* – value	*df*	*p* - value
Treatment	9.77	1, 16	0.0065*
Boot-hold time	4.33	3, 16	0.0205*
Treatment x boot-hold time	2.85	3, 16	0.0705

*Significant ($P < 0.05$)

Summary of Objective 1

- Insect density level in the boot affected the level of insects transferred through the elevator leg to other locations
- Clean grain transferred over infested boots picked-up 1 insect/kg immediately after the transfer, increasing to 2 insects/kg after an 8-week incubation period
- Larger numbers of internally-developing insects were picked up by clean grain flowing over the infested boot, compared to the pick-up of externally developing insects

Summary of Objective 1 (continued)

- Residual insecticide (β-cyfluthrin) reduced insect densities in the boot and the number of insects picked-up by the buckets
- Application of residual insecticide should minimize insect densities and prevent cross contamination of clean grain by residual infested grain in boots

Objective 2: Temporal Changes of Stored-grain Insect Populations

- **Survey of grain facilities:**
  - **3 — Elevators**
  - **3 — Feed mills**

Survey of Facilities in Kansas

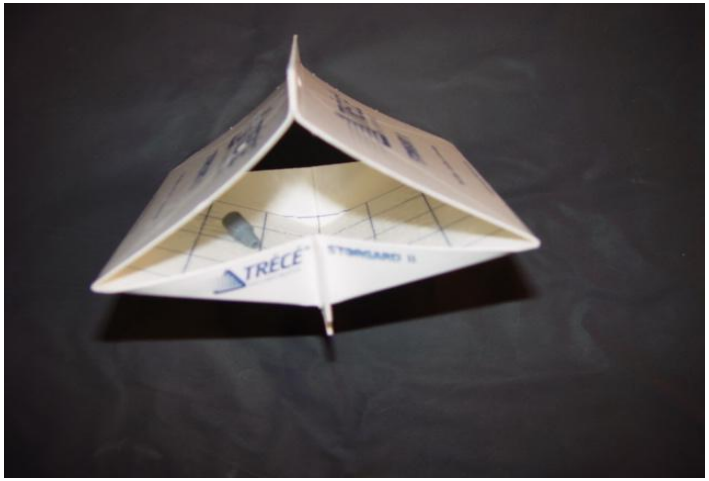
- **Sampling locations:**
  - 3 - Elevator facilities
  - 3 - Feed mill facilities
- **Insect trapping and temperature monitoring:**
  - Pit fall trap for crawling beetles
  - Sticky trap for flying insects
  - Hobo temperature logger
- **Processing of samples**
  - Boot, pit, and load-out areas

Insect Trapping and Temperature Monitoring

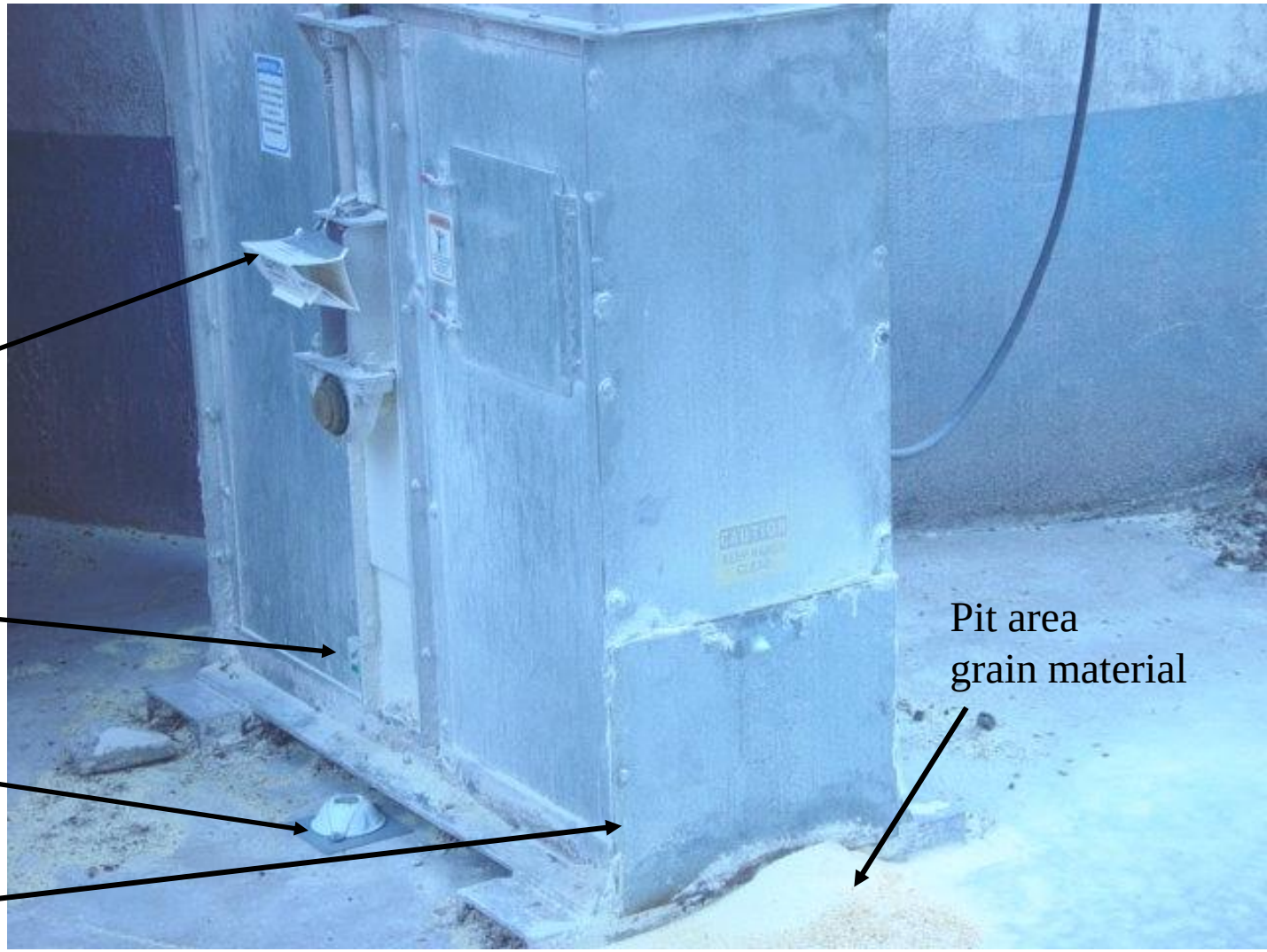
* Dome insect trap.

* Storgard ll insect trap.

* HOBO temperature logger.



Sampling Points in the Boot-pit Area



Relative Abundance of Insect Species in Boot, Pit and Load-out by Facility Type

	% of total live adults in:			
	Elevators		Feed mills	
Species	*2009*	*2010*	*2009*	*2010*
C. ferrugineus	29.4	49.3	4.2	15.4
O. surinamensis	—[b]	0.3	21.2	11.8
S. Oryzae	35.8	23.6	69.2	32.3
T. Castaneum	27.5	22.9	5.2	39.0
Minor spp.[a]	7.3	3.9	0.2	1.5
Total no. adults	1226	1257	6374	3450

[a]Minor species not shown include: *A. advena*, *Carpophilus* spp., *L. oryzae*, *P. ratzeburgi*, *Philonthus* spp., *R. dominica*, *T. variabile*, and *T. stercorea*.

[b]Live adult species were not found in the facility.

Relative Abundance of Insect Species in Pitfall Traps by Facility Type (boot pit area)

	% of total live adults in:[a]			
	Elevators		**Feed mills**	
Species	*2009*	*2010*	*2009*	*2010*
S. Oryzae	51.6	36.2	92.7	31.4
T. Castaneum	30.4	49.6	2.5	17.9
T. Variabile	0.1	41.5	0.4	4.9
Minor spp.[b]	17.6	9.3	4.7	9.2
Total no. adults	250	345	1833	1529

[a]Pheromone-baited pitfall traps for *Tribolium spp.*

[b]Minor species not shown include: *Cryptolestes* spp., *C. angustus*, *O. surinemensis*, P. ratzeburgi, and *T. molitor.*

Relative Abundance of Insect Species in Sticky Traps by Facility Type
(boot pit area)

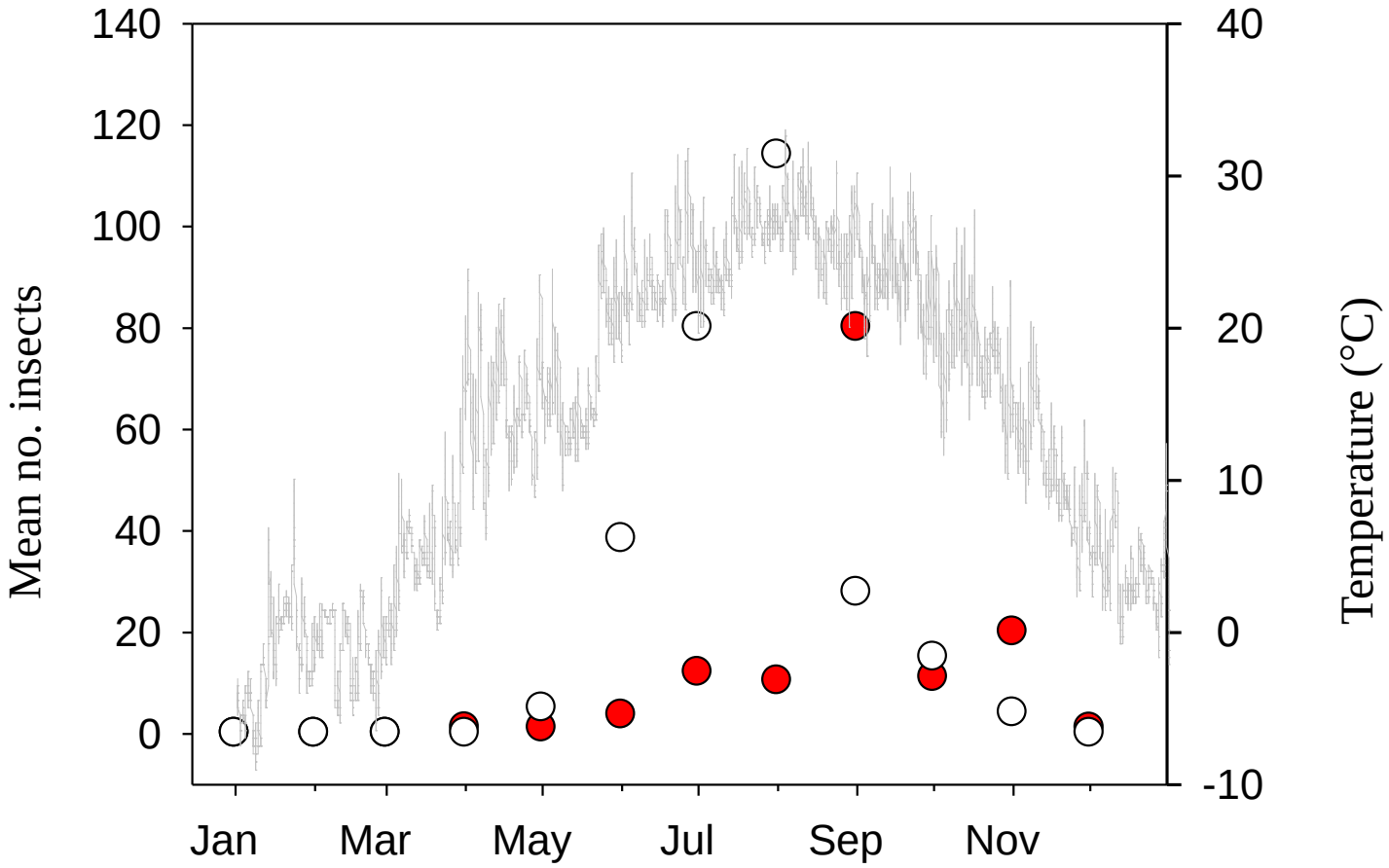
	% of total live adults in:[a]			
	Elevators		**Feed mills**	
Species	*2009*	*2010*	*2009*	*2010*
P. Interpunctella	78.1	60.9	99.8	87.8
R. Dominica	0.4	0.8	0.1	2.6
T. variabile	21.5	38.3	0.1	9.6
Total no. adults	1316	1774	1413	1273

[a]Pheromone-baited sticky traps for *P. interpunctella*, *R. dominica*, and *T. variabile*.

Boot Seasonal Insect Counts and Temperature by Facility Type

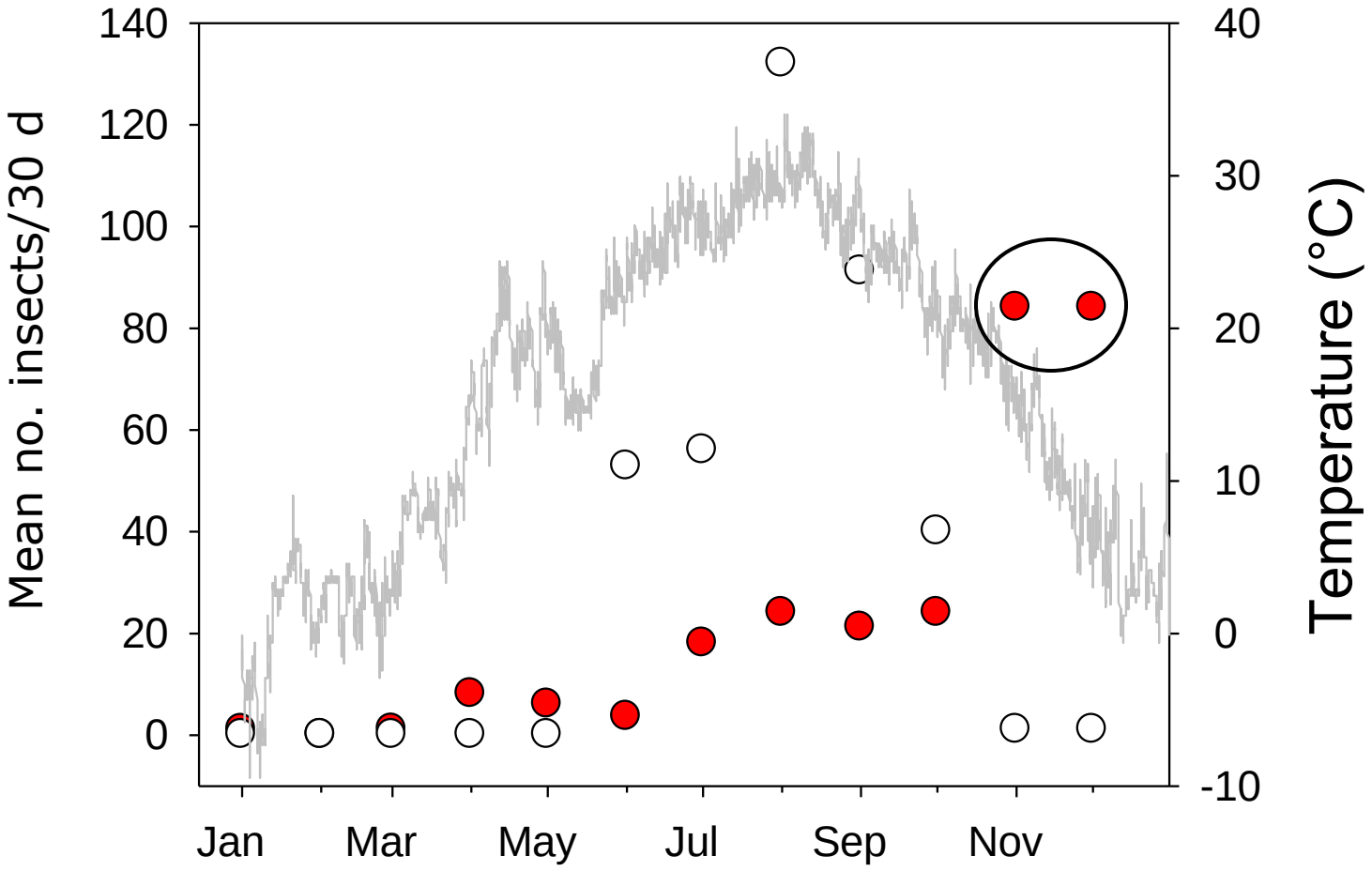
Facility type	Year	Season	Boot (no. insects)	Temperature (°C)
Elevator	2009	Winter	1.0 ± 0.6b	2.6 ± 1.1b
		Spring	3.8 ± 2.3ab	15.7 ± 1.8a
		Summer	18.6 ± 8.9a	19.6 ± 1.3a
		Fall	2.2 ± 1.6b	4.2 ± 1.9b
	2010	Winter	3.9 ± 2.9b	0.3 ± 2.7b
		Spring	2.8 ± 1.1b	18.7 ± 2.1a
		Summer	20.0 ± 4.9a	23.3 ± 1.2a
		Fall	6.3 ± 3.5b	8.9 ± 2..0b
Feed Mill	2009	Winter	0.3 ± 0.3b	5.7 ± 0.0 d
		Spring	0.6 ± 0.3	17.8 ± 0.2b
		Summer	20.3 ± 13.2a	23.5 ± 1.0a
		Fall	3.0 ± 2.1a	9.2 ± 0.8c
	2010	Winter	1.5 ± 0.8b	2.5 ± 0.7d
		Spring	73.7 ± 44.7ab	19.2 ± 0.7b
		Summer	95.4 ± 34.9a	26.3 ± 0.6a
		Fall	60.7 ± 13.3a	11.1 ± 0.2c

Adult Insect Counts from Feed Mill A Pitfall and Sticky traps (2010)



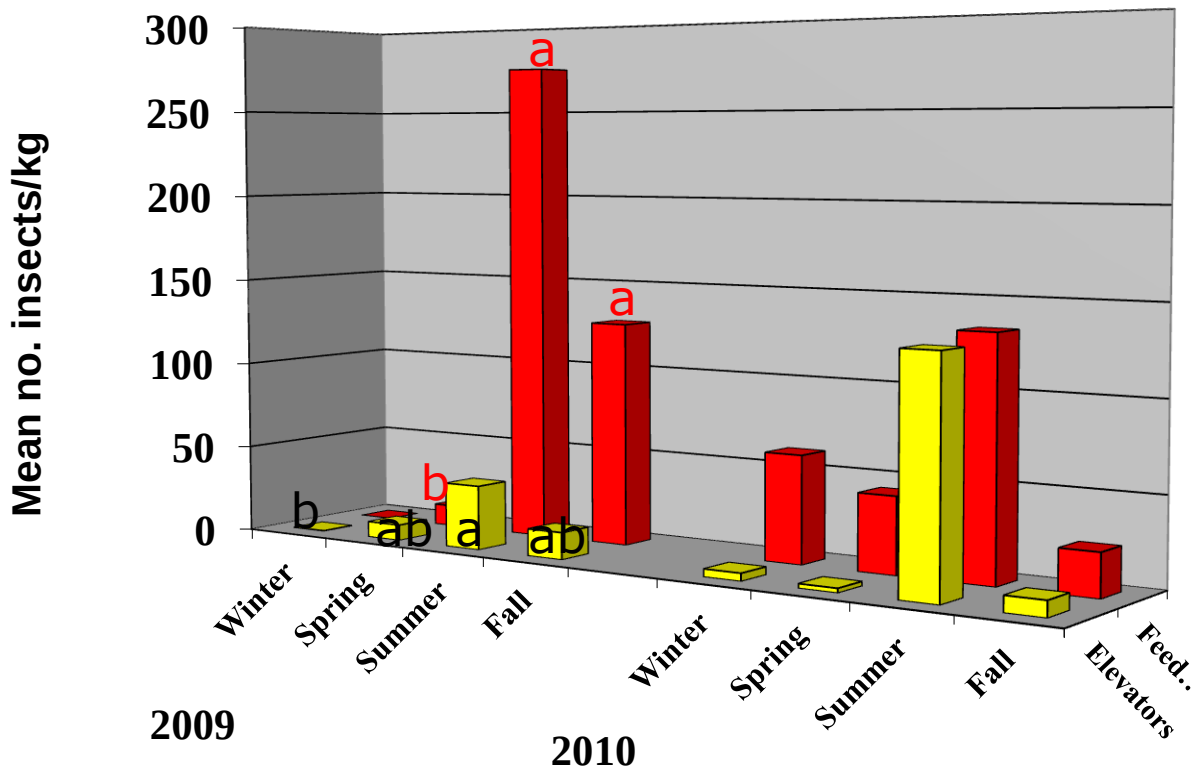
Solid (red) marker is pitfall traps and open circles are sticky traps.

Adult Insect Counts from Feed Mill B Pitfall and Sticky Traps (2010)



Solid (red) marker is pitfall traps and open circles are sticky traps.

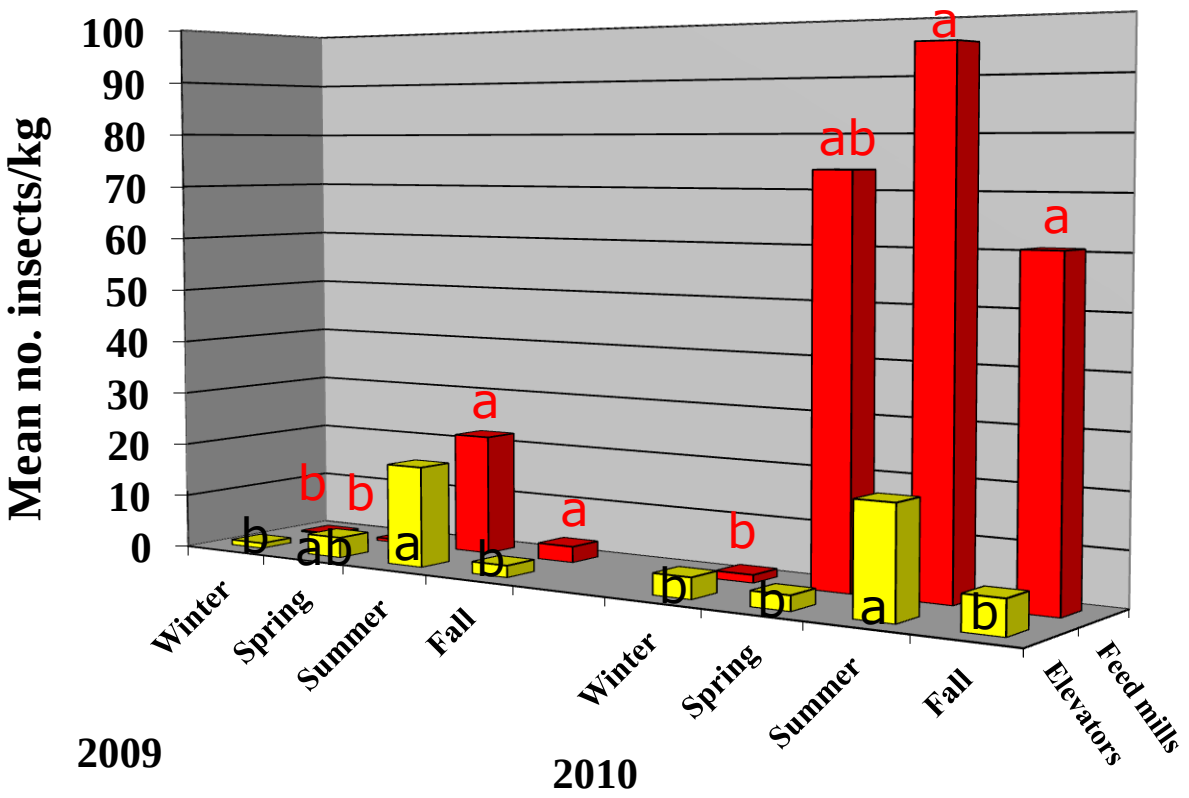
Seasonal Average Insect Densities — Pit Area



Facility type	Calendar period	F-value	df	*P*-value
Elevators	Year	1.87	1, 64	0.7378
	Seasons	9.24	3, 64	**0.0002***
	Year x seasons	1.50	3, 64	0.9316
Feed Mills	Year	0.23	1, 61	0.1326
	Seasons	11.65	3, 61	**0.0002***
	Year x seasons	6.81	3, 61	**0.0005***

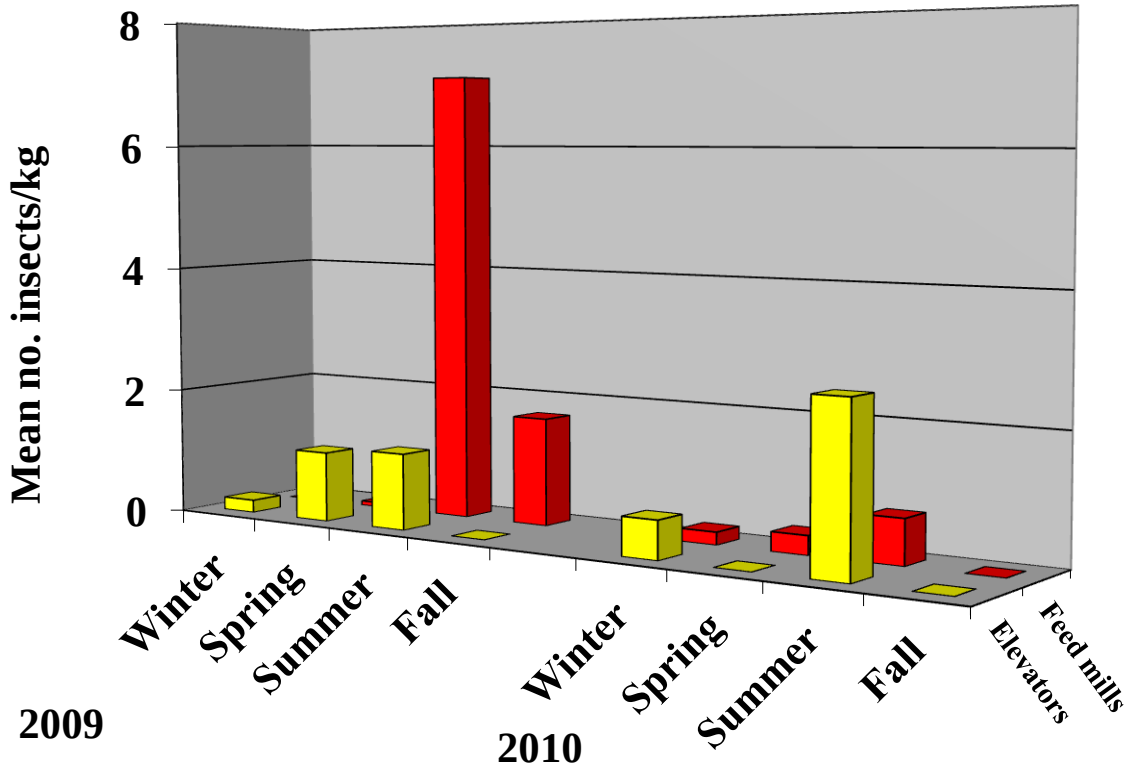
*Significant ($P < 0.05$)

Seasonal Average Insect Densities — Boot Area



Facility type	Calendar period	*F*-value	df	*P*-value
Elevators	Year	0.11	1, 64	0.1763
	Seasons	7.41	3, 64	**0.0002**
	Year x seasons	0.15	3, 64	0.2290
Feed Mills	Year	30.47	1, 61	**0.0001**
	Seasons	6.71	3, 61	**0.0005**
*Significant ($P < 0.05$)	Year x seasons	0.21	3, 61	0.0553

Seasonal Average Insect Densities — Load-out Area

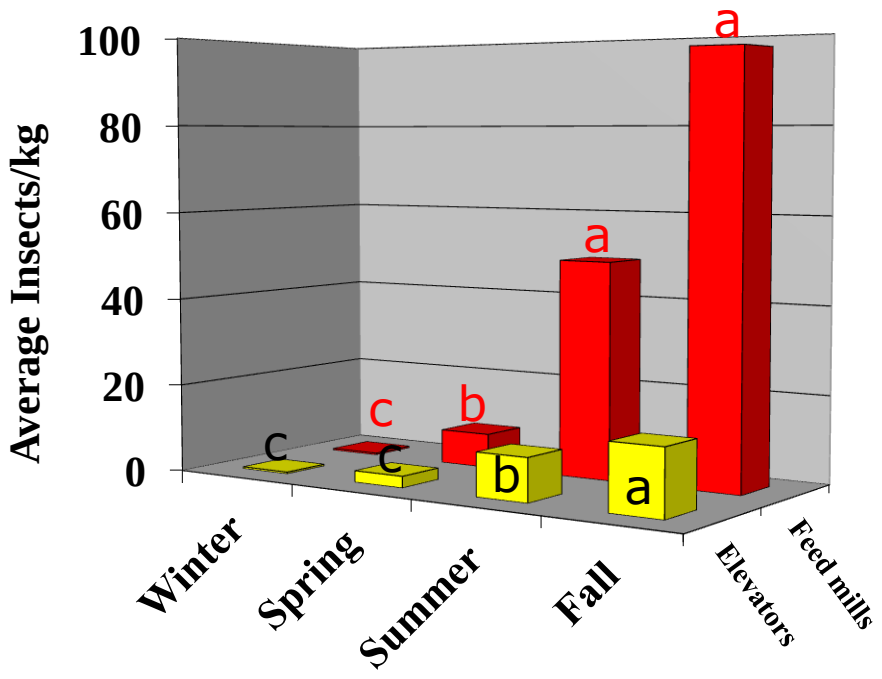


Facility type	Calendar period	*F*-value	df	*P*-value
Elevators	Year	1.25	1, 40	0.2528
	Seasons	1.71	3, 40	0.1800
	Year x seasons	0.25	3, 40	0.7582
Feed Mills	Year	2.32	1, 33	0.6347
	Seasons	0.64	3, 33	0.0807
	Year x seasons	2.67	2, 33	0.8111

*Significant ($P < 0.05$)

Adult Insect Species Collected from Pitfall Traps

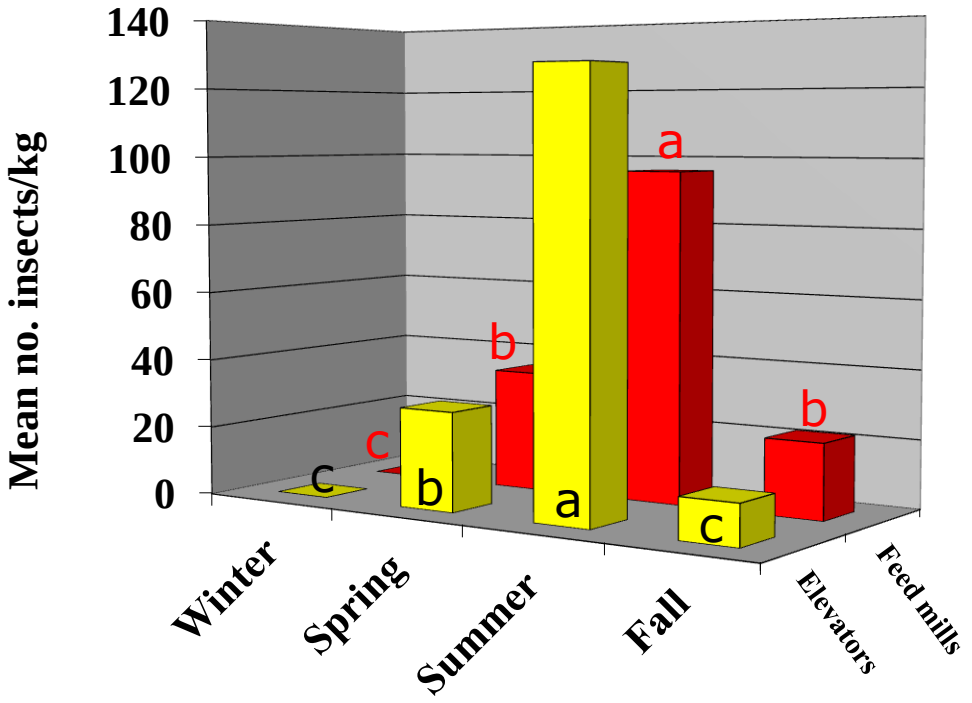
located in the pit area of 3 elevator and 3 feed mill facilities during 2009-10



Facility type	Calendar period	*F*-value	df	*P*-value
Elevators	Year	0.03	1, 58	0.5463
	Seasons	7.61	3, 58	**0.0002**
	Year x seasons	0.61	3, 58	0.1251
Feed Mills	Year	2.05	1, 57	0.1034
	Seasons	10.89	3, 57	**0.0001**
*Significant ($P < 0.05$)	Year x seasons	0.19	3, 57	0.8724

Adult Insect Species Collected from Sticky Traps

located in the pit area of 3 elevator and 3 feed mill facilities during 2009-10



Facility type	Calendar period	*F*-value	df	*P*-value
Elevators	Year	0.37	1, 58	0.8576
	Seasons	31.47	3, 58	**0.0002**
	Year x seasons	1.99	3, 58	0.6143
Feed Mills	Year	2.74	1, 57	0.1582
	Seasons	23.35	3, 57	**0.0001**
*Significant ($P < 0.05$)	Year x seasons	0.23	3, 57	0.9026

Summary of Objective 2

- Weevils (*S. oryzae*) were the most prevalent insect pests collected
- Other commonly collected insect species included: *T. castaneum*, *C. ferrugineus*, and *O. surinamensis*
- Boot and pit cleaning is critical in preventing pest population explosions during the warm summer months

Objective 3: Economic Analysis of Insect Commingling

- **Development of a partial budget:**
  - Budget for only one part of the facility
  - Framework of a planning and decision-making process
  - Compare costs and benefits of a feed mill and elevator operation
- **Development of a stochastic dominance model**
  - Compares relative risk levels between alternatives
  - A framework useful for decision-making process
  - Used to compare alternative risky choices

Partial Budget Analysis

- **Planning and decision-making framework used to compare costs and benefits of a business decision**
- **Typically four categorical parts**
  - Additional income
  - Reduced costs
  - Reduced income
  - Additional costs

Partial Budget Analysis

costs and income associated with commingling insect levels in an elevator leg boot following a chemical spray treatment

Added income	Amount	Added costs	Amount
Grain discounts ($0.08 per bu.)	$17.70	Labor ($12.50/h x 0.5 h)	$6.25
Transportation (rejected load, $0.038 per bu.)	$8.97	Chemical spray (per slip-boot)	$2.18
Reduced costs	**Amount**	**Reduced income**	**Amount**
None		None	
Subtotal	$26.67	Subtotal	$8.43

Net change: $18.24 (subtotal from column 1 minus subtotal from column 2) or approximately 0.08 cents per bushel.

Partial Budget Analysis

Costs and income associated with commingling insect levels in an elevator leg boot loaded with insect-free grain

Added income	Amount	Added costs	Amount
Grain discounts ($0.102 per bu.)	$23.99	Labor ($12.50/h x 0.5 h)	$6.25
Transportation (rejected load, $0.038 per bu.)	$8.97		
Reduced costs	**Amount**	**Reduced income**	**Amount**
None		None	
Subtotal	$32.96	**Subtotal**	$6.25

Net change: $26.71 (subtotal from column 1 minus subtotal from column 2) or approximately 11.3 cents per bushel.

Stochastic Dominance Modeling

- **Means of comparing alternative risky choices are separated into two groups, those that should not be taken because they are dominated by or are less preferred to a second group which is not dominated**

- **Types of Stochastic Dominance**
  - First Degree (FSD, more is preferred to less)
  - Second degree (SSD, more discriminating and assumes the decision-maker is risk averse)
  - With respect to a function (decision-maker is absolute risk averse with upper and lower boundaries)

Stochastic Dominance Modeling

- **A PC based program performed FSD, SSD, and SD with respect to a function, and analyzed risk associated with insects harboring in the boot (Goh et al., 1989)**

- **Input data was from applied grain (corn and wheat) discounts**
  - Grain quality factors
  - Live adult insect counts
  - Insect damaged kernels

Stochastic Dominance Modeling

- **Applied corn quality discounts were from:**
  - Moisture Content (MC)
  - Test Weight (TW)
  - Broken Corn and Foreign Material (BCFM)
  - Total damage material
  - Number of adult insects/kg of grain.
- **Applied wheat quality discounts were from:**
  - Moisture Content (MC)
  - Test Weight (TW)
  - Shrunken and Broken Kernels
  - Total damage material
  - Insect Damage Kernels (IDK)
  - Number of adult insects/kg of grain.

Risk Analysis of Wheat Quality Discounts

Stochastic Dominance Modeling

	Applied wheat quality mean discounts (cents/bu)							
Density (insects/kg)	MC	TW	FM	S&B	Damage	IDK	Insects	Discounts (cents/bu)
Insect-free and untreated slip-boots (A)								
0	0	0.04	0	0	0	0	0	0.04
Infested and untreated slip-boots (B)								
600	0	0.05	0	0	0.04	0	0.05	0.14
Infested and insecticidal spray treated slip-boots (A)								
600	0	0.04	0	0	0.02	0	0	0.06

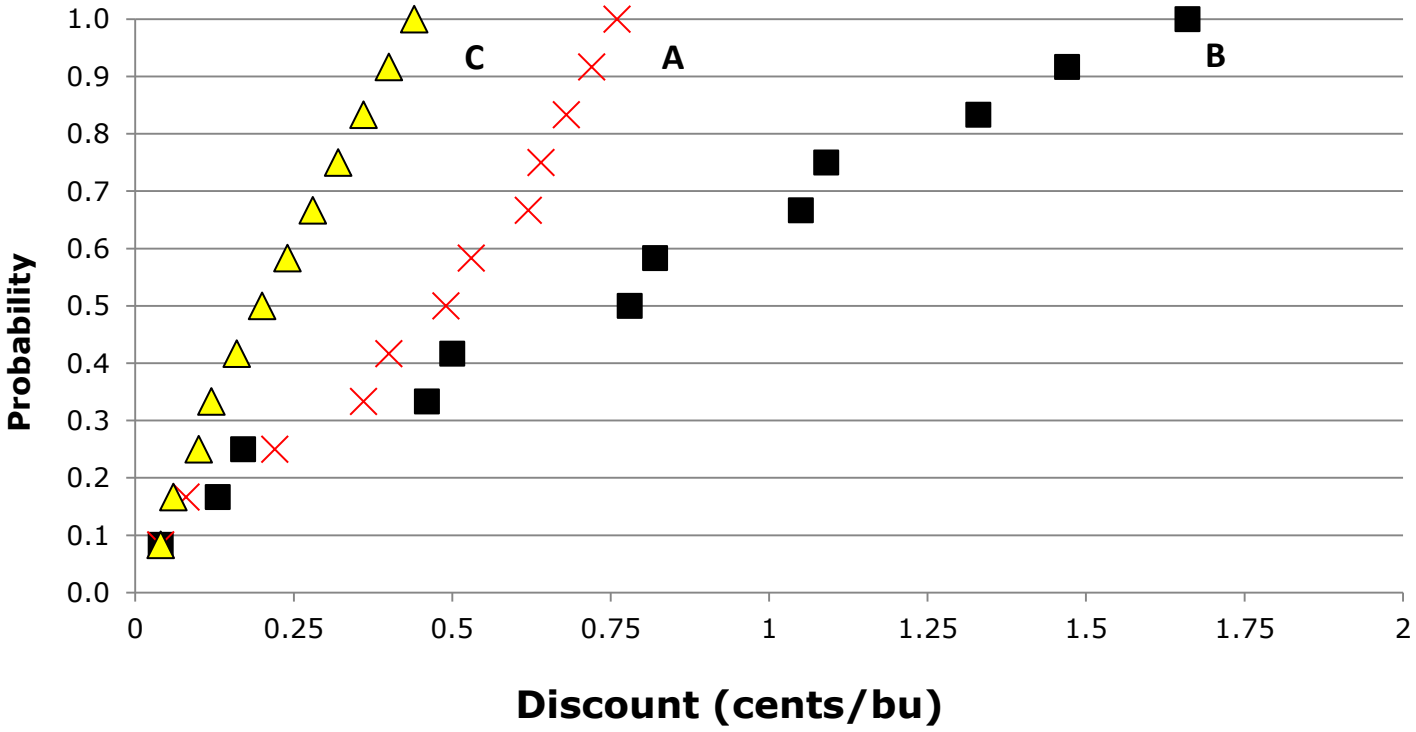
Risk Analysis of Corn Quality Discounts

Stochastic Dominance Modeling

	Applied corn quality mean discounts (cents/bu)					
Density (insects/kg)	MC	TW	BCFM	Damage	Weevil infested	Discounts (cents/bu)
Insect-free and untreated slip-boots (A)						
0	0	0	0	0	0	0.00
Infested and untreated slip-boots (B)						
600	0.04	0	0	0	0.03	0.07
Infested and insecticidal spray treated slip-boots (B)						
600	0.02	0.01	0	0.01	0.03	0.06

Risk Analysis of Wheat Quality Discounts

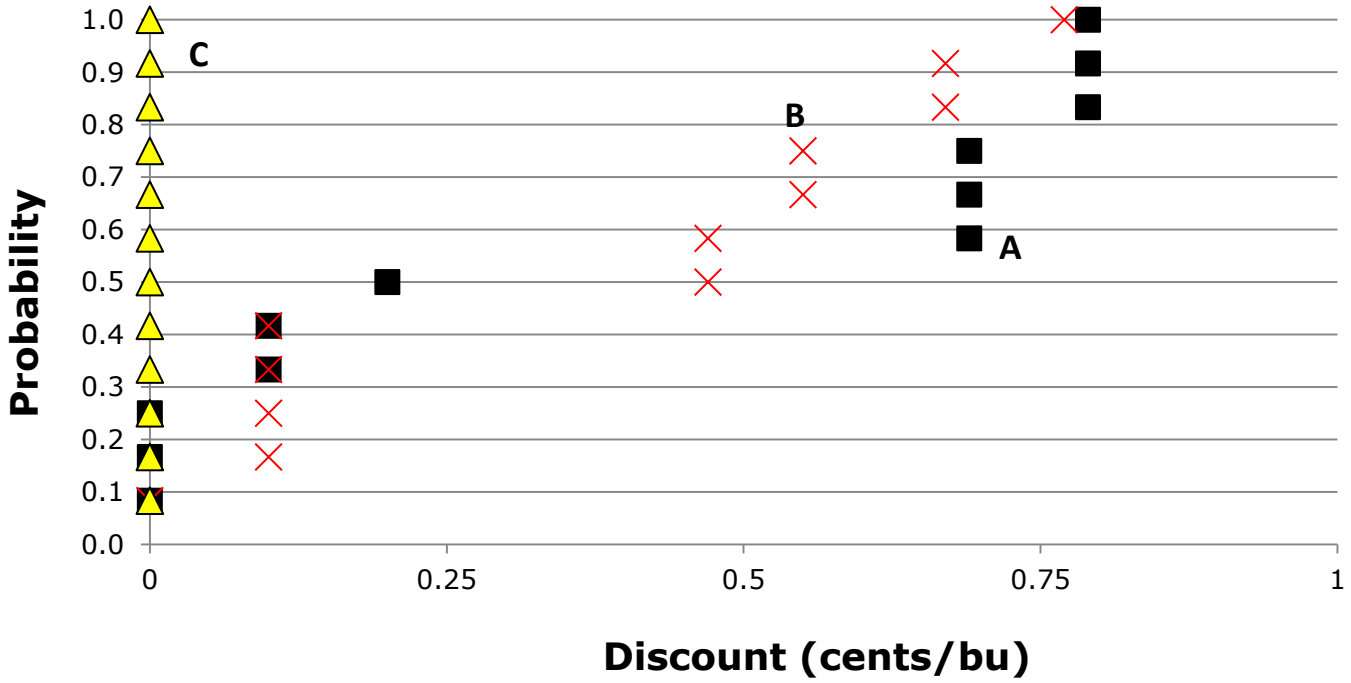
Stochastic Dominance Modeling



A: Infested and insecticidal spray treated slip-boots
B: Infested and untreated slip-boots
C: Control: insect-free and untreated slip-boots

Risk Analysis of Corn Quality Discounts

Stochastic Dominance Modeling



A: Infested -insecticidal spray treated slip-boots
B: Infested and untreated slip-boots
C: Control: insect-free and untreated slip-boots

Summary of Objective 3

- Partial budget analysis and S-D risk modeling indicate that boot sanitation every 30 days avoids costly grain discounts and is the preferred choice by operators and managers of elevator and feed mill facilities
- Boot sanitation always had lower insect pest populations in the boot residual grain, providing higher facility operational net income without the use of chemicals

Conclusions

- New facility pest management sanitation guidelines of the boot and pit area include:
  - Boot residual grain clean-out every 30 days
  - Removal of grain spillage and floor sweepings from pit area
  - Proper disposal of boot and pit residual grain
- These guidelines could be used to improve elevator and feed mill insect pest management programs
- Slip-boot design could easily be adapted to bucket elevator leg design, improving boot sanitation and reducing operational costs

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Questions